ANFIS Based Speed Control of DC Motor

Himanshu Chaudhary
Research Scholar, Department of Electrical Engineering, Jamia Millia Islamia,
New Delhi-25, India

Shahida khatoon
Prof., Department of Electrical Engineering,
Jamia Millia Islamia,
New Delhi-25, India

Ravindra Singh
Scientist 'G', LASTEC,
DRDO, New Delhi, India

Abstract — **This paper presents comparative analysis of different controller configuration for speed control of separately excited DC motor. The main aim of this paper is to obtain optimize speed characteristics of DC motor drive by minimizing transient response specification such as rise time, settling time and overshoot. The speed control of DC motor is done using PID, Fuzzy and ANFIS controller Configuration. PID controller tuning parameters are obtained using Ziegler Nicholas (ZN) and Modified Ziegler Nicholas (MZN) method. This PID configuration is used as a reference to develop Fuzzy and Anfis structure. In this study, transfer function based model of DC motor is developed with defined parameters which is then integrated with different controller configuration. Finally, the developed system is tested for number of simulation runs and comparative analysis shows that ANFIS provide superior features including easy implementation, good computational efficiency, and stable convergence characteristic and this has validated the robustness of the ANFIS scheme.**

Keywords— DC motor, Modified Zeigler Nicholas, PID controller, Fuzzy Control, Adaptive Neuro fuzzy inference system (ANFIS).

I. INTRODUCTION

The motor and its control mechanism markets are thriving in almost every industrial applications particularly medical and robotics. Because of their variable characteristics, they are extensively used in variable speed drives. Now a days, utmost requirements of modern industries are to provide wide range position or speed control to the designed system. Both brush dc motors and brushless dc motors can satisfy the requirements. DC Motor can provide high starting torque with possibility of fine speed control over wide range. A classical DC motor with brushes provides a simplified efficient and inexpensive solution but it never seems to be reliable enough because of the existence of collector and brushes. While In BLDC, rotor is the sole bearer of the magnets, it requires no power, i.e. no connection, no commutator, and no brushes. In place of these, brushless motor employs control circuitry and hence can avoid the problem caused by mechanical commutators.

Because of its wider use and simplified implementation of its mathematical model comparing with other types of electrical machines, DC motor is widely studied in academics programmes and encountered in almost every book and manual irrespective of target audience in field of automation and control.

Akons and Alexandrovitz developed a mathematical model for brushless DC motor and studied the dynamic behavior under changing condition. A.M. Kassem, O. Atlam [1] [2] have gone through different application aspects of DC motor in field of renewable energy, especially in system involving different configuration of solar panel movement: one or two axis orientation.

DC motor application in electrical vehicle/automated vehicle dates since some time ago. Advantage of using DC motor in electrical vehicle includes its mechanical characteristics, no slip between tires and road. Beside traction application several researchers finds its application in vehicle automation, different types of actuators, UAV's, suspensions system, two wheel autonomous ground vehicle, medical actuators.

Earlier J.M. hilkert and Masten [3] have explained DC motor application in systems driving Gimbal Assembly in order to hold and control line of sight of one object relative to another object or inertial space. Further, in unique three axis gimbal mechanism [4], two axis head mirror rotation [5] or wherever rotation of gimbal or mirror involved, brushless DC motor played its part successfully.

Surveying the wide application of DC motor, Several control theories have been developed so far to obtain desired speed trajectory of DC motor. R. Mondal et all., beautifully explained closed loop DC motor speed control mechanism based on 8051 microcontroller with both software and hardware implementation [6]. A. T. Alexandridis and G. C. Konstantopoulos presented a modified nonlinear PI speed controller that significantly enhanced the dynamic performance of series excited DC motor [7]. H. Butler, G. Honderd [8], F. Beltran Carbajal et all [9], proposed different control mechanism aiming to compensate output tracking error for DC motors. Further, PID control configuration of DC motor is proposed by several researchers. The reason of acceptability is for its simple structure , good reliability and robustness. But to determine and optimize those PID parameters is always remains a challenging task. The Zeigler-Nicholas technique is only perhaps the well known tuning method. In 1942 Based on time response characteristics and experience, Zeigler Nicholas proposed tuning formulas. Although it lacks selections of parameters and has an excessive overshoot , still opens the way for generation to come. Modified Zeigler Nicholas algorithm based on Chien Hrones Reswick tuning, Cohen-Coon formula, Wang-Juang-Chan formula, refined Ziegler-Nichols tuning, and Zhuang-Atherton optimum PID for set point regulation, can overcome the drawback of Zeigler Nicholas.

M. Knudsenand [10], A.. Al. Qassar, M. Z. Othman [11], A. A. Bature et all, [12], M. Abdelati and M. S. Salah [13] have contributed immensely to determine DC motor parameters for use in present day application. The other modern control algorithm which gain so much popularity in last few year includes: Fuzzy, Neural, Genetic algorithm and other evolutionary technique. So, It would be wise to extend the

978-1-4673-9080-4/16/$31.00 ©2016 IEEE

control studies on DC motor aiming towards obtaining desired speed trajectory.

The remaining of the paper is structured as follows: Section II describes Mathematical modeling of DC motor followed by formulation of its transfer function. In Section III Modeled transfer function is being integrated with different controller configurations in order to obtain desired path. In Section IV effectiveness of the controllers and analyzed and compared followed by conclusion.

II. DC MOTOR MATHEMATICAL MODEL

In recent times, DC motors becomes one of the most widely used prime movers in many industrial application because of its inherent straight forward characteristics and stability. This paper focuses on linear speed control of DC motor, and therefore separately excited DC motor is considered which is most often used in position adjustment and velocity tuning. The Schematic of separately excited DC motor is shown in fig. 1.

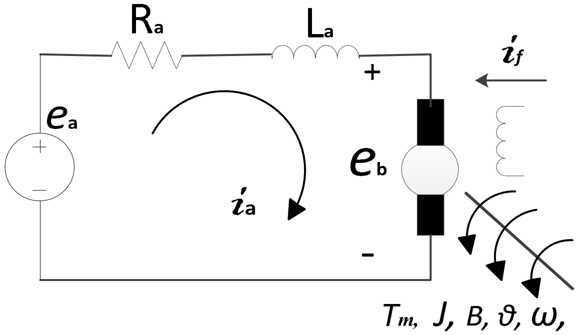


Fig. 1. Schematic of DC motor (Separately Excited)

Where ;

e_a : Applied Voltage (V)
e_b : Induced Emf
i_a : Armature current
i_f : Field Current
R_a : Armature resistance
L_a : Armature Inductance
ω : Angular velocity of rotor
J : Rotor Inertia
B : Friction Constant
K_b : Back Emf Constant
K_t : Torque Constant
T_r : Torque (Motor)

Applying KCL in armature loop we can get :

$$R_a\, i_a(t) + L_a \frac{di_a}{dt} + e_b(t) = e_a(t) \tag{1}$$

As, when the armature continues to rotate due to motor action, armature conductors cuts the magnetic field and therefore emfs are induced in them. Hence this e_b is directly proportional to speed ω.

$$e_b(t) = K_b\, \omega(t) = K_b \frac{d\vartheta}{dt} \tag{2}$$

Motor torque can be obtained based on newton's law :

$$T_r(t) = J\frac{d^2\vartheta}{dt} + B\frac{d\vartheta}{dt} = K_t i_a(t) \tag{3}$$

Considering Laplace of all three above equations, they can be formulated as :

$$(R_a + SL_a)I_a(s) + E_b(s) = E_a(s) \tag{4}$$

$$E_b(s) = K_b\, \omega(s) = SK_b\vartheta(s) \tag{5}$$

$$T_r(s) = SJ\vartheta(s) + B\vartheta(s) = K_t I_a(s) \tag{6}$$

Block Diagram representation of above equation is as follows :

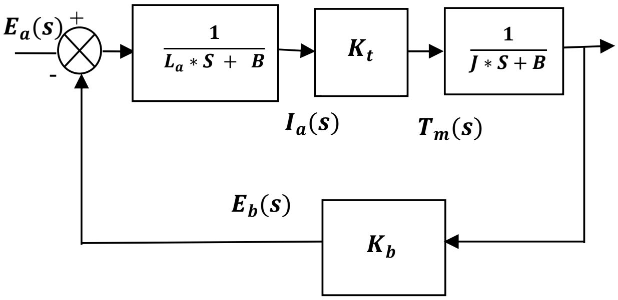


Fig. 2. Armature Control DC motor Block Diagram

Above Block diagram can be formulated in transfer function as :

$$\frac{\omega(s)}{E_a(s)} = \frac{K_t}{(SL_a + R_a)(JS + B) + K_t K_b}$$

Standard test model parameters considered for this simulation study are listed as :

TABLE I. DC MOTOR MODEL PARAMETER

Parameters	Values
Resistance (Armature)	3.3 ohm
Inductance (Armature)	0.00464 H
Rotor Inertia	9.64e-6 Kg m^2
Friction Constant	1.8e-6 Nms/ rad
Torque Constant	0.028 Nm/ A
Back Emf Constant	0.028 Vsec/ rad

Hence, Transfer function becomes :

$$G(s) = \frac{0.028}{0.0447296e(-6)\, S^2 + 0.00838381S + 0.0007899}$$

III. CONTROLLER CONFIGURATION

In this part, a simplified transfer function of DC motor based on electrical mechanical equation is integrated with three controller configuration.

- PID controller based on Modified Zeigler Nichols
- Fuzzy Control Algorithm
- Adaptive neuro fuzzy inference system

A. PID Controller

A typical PID controller structure is shown in Fig. 3, where resulting difference of desired and feedback signal generates error signal e(t), which is further used to drive the proportional, integral and derivative action with the resulting signals weighted and summed to form the control signal u(t) applied to plant model.

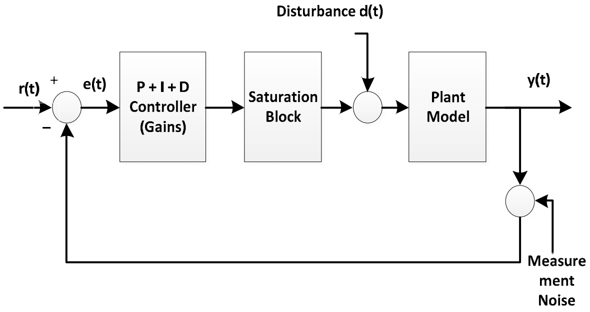


Fig. 3. Typical PID Controller Block Diagram

Mathematically, it can be structured as:

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int e\,(t)\,dt + T_d\frac{d}{dt}e(t)\right]$$

And its Laplace transfer representation is:

$$U(s) = K_p\left(1 + \frac{1}{T_i s} + \frac{sT_d}{1 + s\frac{T_d}{N}}\right)E(s)$$

Where ;

K_p : Proportional Gain
T_i : Integral time constant
T_d : Derivative time constant
N : Filter Co-efficient

Tuning of these K_p, T_i, T_d parameters are of utmost concern, as it always seems a mystery while designing the controller. The stability and responsiveness of a process seem to be at complete odds with each other. So there is a need to find Acceptable stability. Zeigler Nicholas and its variants are only perhaps the well known technique available so far. Modified Zeigler Nicholas based on Chien Hrones Reswick (CHR) tuning algorithm is adopted in this work. CHR emphasizes on disturbance rejection or set point regulation. In addition to that, other qualitative characteristics like responsiveness and transient state oscillations can be accommodated. CHR tuning formulae are given in Table II.

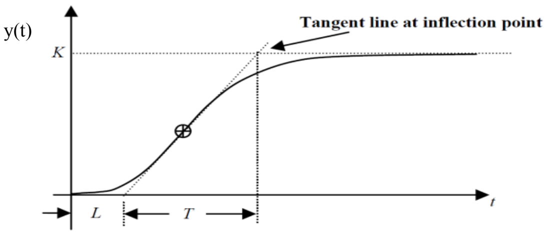


Fig. 4. Typical PID Response Characterisitc Curve

TABLE II. MODIFIED ZEIGLER NICHOLAS TUNING FORMULAE

Type of Control law	K_p $(Proportional)$	T_i *(Integral)*	T_d $(Derivative)$
P	$\frac{0.7}{a}$		
PI	$\frac{0.6}{a}$	T	
PID	$\frac{0.95}{a}$	1.4 T	0.47 L

Where, parameters K, L, T can be extracted from experimental response characteristic curve, as shown in Fig 4. These values can be used to form PID controller transfer function, which then can be integrated with DC motor plant dynamics.

B. Fuzzy Control Algorithm

In Fuzzy logic, partial truth are included to extend bi-valued logic which then become an extension to classical control theory and proven to be more robust and optimized [15]. When the available information is uncertain, imprecise, incomplete or vague in all respect, Fuzzy set theory comes with a mathematical tools for carrying out approximate reasoning process when available information is uncertain, imprecise, in-complete or vague. Fuzzy logic system gives a simple, if-then rule based approach to solve a control problem instead of modeling a system mathematically. It works based on availability of error data set and significant rate of change of error data set, which is then fuzzified based on certain membership function followed by if-then rules.

$$e(t) = r(t) - u(t)$$

$$de(t) = e(t) - e(t-1)$$

Fuzzy logic control Block Diagram is shown in Fig. 5.

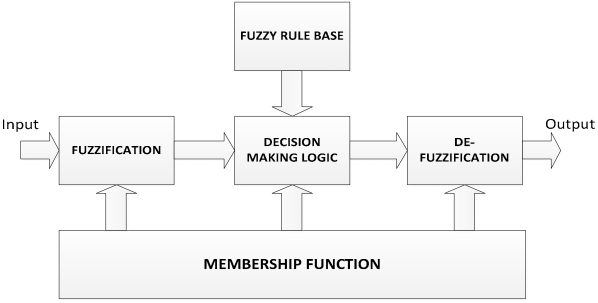
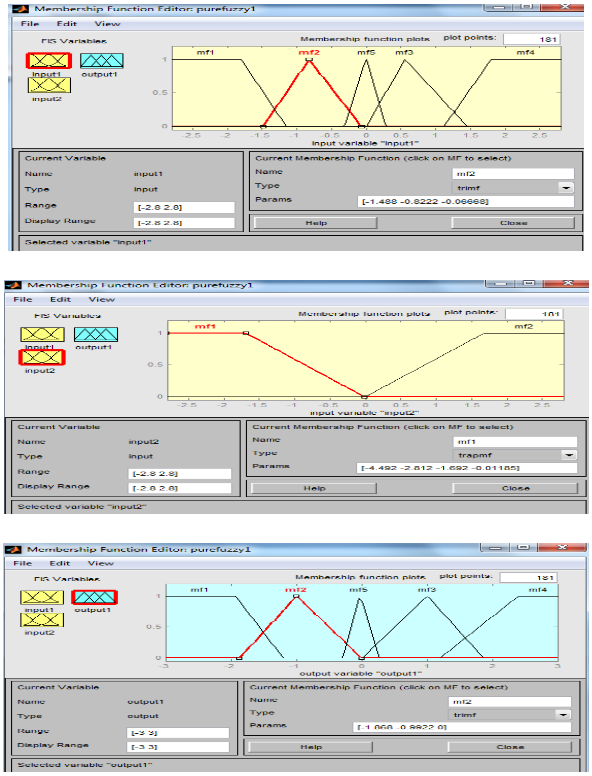


Fig. 5. Fuzzy Logic Development Algorithm



plot points: 181

Current Variable: Name input1; Type input; Range [-2.8 2.8]; Display Range [-2.8 2.8]
Current Membership Function (click on MF to select): Name mf2; Type trimf; Params [-1.488 -0.8222 -0.06668]
Selected variable "input1"

Current Variable: Name input2; Type input; Range [-2.8 2.8]; Display Range [-2.8 2.8]
Current Membership Function (click on MF to select): Name mf1; Type trapmf; Params [-4.492 -2.812 -1.692 -0.01185]
Selected variable "input2"

Current Variable: Name output1; Type output; Range [-3 3]; Display Range [-3 3]
Current Membership Function (click on MF to select): Name mf2; Type trimf; Params [-1.868 -0.9922 0]
Selected variable "output1"

Fig. 6. Membership Functions (a) Input 1 (b) Input 2 (c) Output

C. *ANFIS Scheme*

Artificial Neural Network always proven to have strong learning capabilities at numerical level while Fuzzy system provides good capability of interpretation and can also integrate experts knowledge. The hybridization of both technique so far, is assumed to capture merits of both systems. And hence ANFIS comes as new tool.

In this configuration, Tagani Sugeno fuzzy inference file has been generated based on the error and its derivative as input variables, each consisting of five membership function with a total of twenty five possible combination of rules. The input and output data set has been derived from designed PID controller tuned using MZN. The structure of ANFIS model for tracking the desired speed control path is shown in Fig. 7.

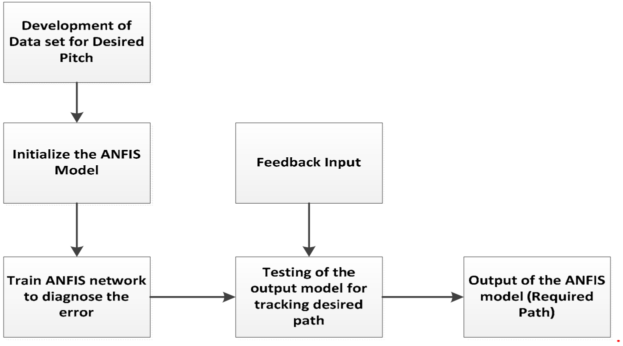
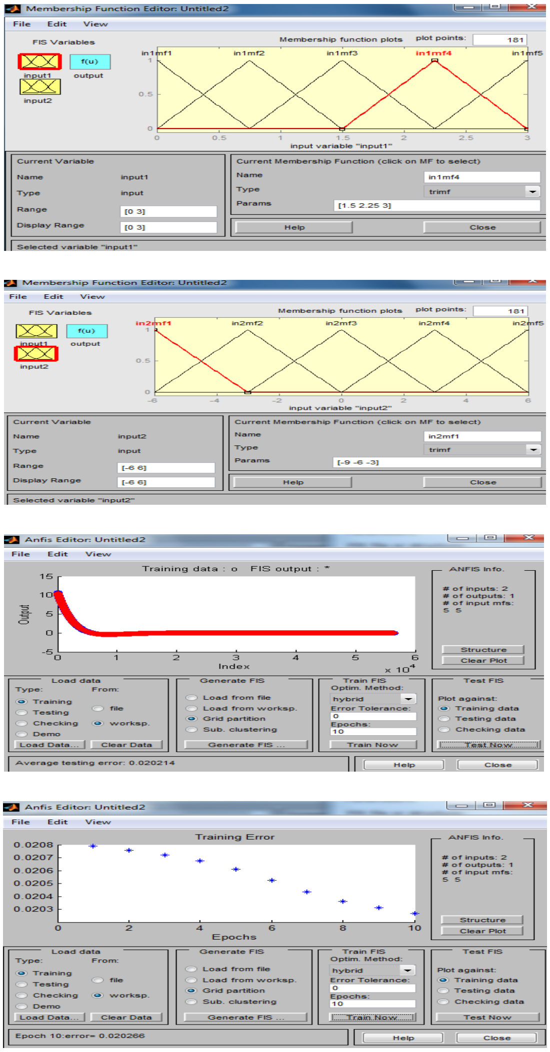


Fig. 7. ANFIS Model Structure



plot points: 181

Current Variable: Name input1; Type input; Range [0 3]; Display Range [0 3]
Current Membership Function (click on MF to select): Name in1mf4; Type trimf; Params [1.5 2.25 3]
Selected variable "input1"

Current Variable: Name input2; Type input; Range [-6 6]; Display Range [-6 6]
Current Membership Function (click on MF to select): Name in2mf1; Type trimf; Params [-9 -6 -3]
Selected variable "input2"

ANFIS Info.
# of inputs: 2
# of outputs: 1
# of input mfs:
5 5

Load data — Type: ● Training ○ Testing ○ Checking ○ Demo; From: ○ file ● worksp.
Generate FIS — ○ Load from file ○ Load from worksp. ● Grid partition ○ Sub. clustering
Train FIS — Optim. Method: hybrid; Error Tolerance: 0; Epochs: 10
Test FIS — Plot against: ● Training data ○ Testing data ○ Checking data

Average testing error: 0.020214

Epoch 10:error= 0.020266

Fig. 8. A) membership function (input 1), b) membership function (input 2), c) Training Data d) Error data

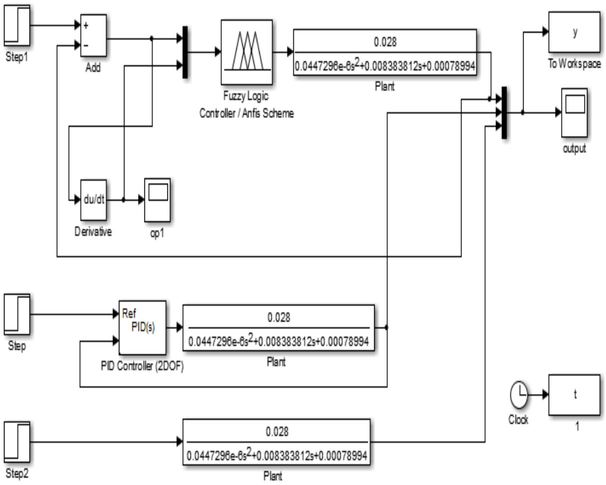


Fig. 9. Complete Simulation Diagram

IV. RESULTS AND DISCUSSION

Output response characteristics of complete integrated DC motor are shown in Fig. 10. It is clearly observed that response out of ANFIS integration is very fast with minimal or no overshoot, very less settling time and zero steady state error. The PID parameters simulation values of a, L, T and K_p, T_i, T_d, out of modified Ziegler Nicholas estimation are observed to be : 0.04798, 4.25, 88.57 & 30.094, 124.998, 20.148 respectively.

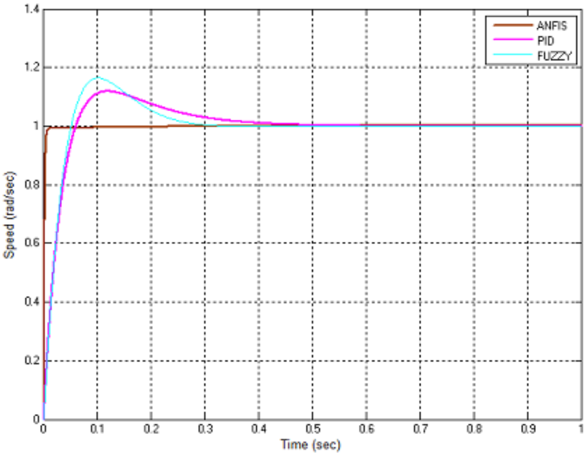


Fig. 10. Comparative Output Characteristics Graph

TABLE III. COMPARATIVE ANALYSIS

Method.	PID Control (MZN)	Fuzzy Logic	ANFIS
Peak Time (seconds)	0.12	0.1	0.02
Rise Time(seconds)	0.1	0.86	0.01
Settling Time (seconds)	0.5	0.3	0.02
Gain Margin	Inf	Inf	Inf
Maximum Overshoot (%)	14.2	18.9	Minimal or no overshoot

V. CONCLUSION

Focus of this work is to gain better understanding of DC motor Dynamics along with its control mechanism to develop a perfect simulator platform. The simplified DC motor model dynamics are observed to be very non linear. It is therefore integrated with several controller configurations. Among different controller configurations simulated in this paper, ANFIS proven to be more optimized. The developed model is tested through number of simulation run that validate the accuracy of dynamic model and robustness of the proposed controller.

REFERENCES

[1] Kaseem, A.M. (2012), "MPPT Control Deisgn and Performance Improvement of a PV Generator Powered DC Motor-pump System based on Artificial Neural Netowrks", *International Journal of Electrical Power and Energy Systems*, Vol. 43, No. 1, pp. 90–98, Dec. 2012.

[2] Altam, O. and Kolhe, M. (2013), "Performance Evaluation of Directly Photovoltaic Powered DC PM (Direct Current Permanent Magnet) Motor–Propeller Thrust System", *Energy*, Vol. 57, pp. 692–698, Aug. 2013.

[3] Hilkert, J.M. (2008), "Inertially Stabilized Platform Technology-Concept and Principles", *IEEE Control System Magzine*, pp. 26–46, February 2008.

[4] Hilkert, J.M. and Jonas, M. (2008), "A Unique Three Axis Gimbal Mechanism", *Proc SPIE (Society of Photo Instrumentation Engineers)*, Vol. 8906, pp. 69710E-1–69710E-8.

[5] Xiao-ming, L., Jian, S., lei, B. and Li-Xin, M. (2011), "Maths Anaysis of Two Axis Rotation Mirror Course Tracking System for Laser Communication", *Proc. SPIE (Society of Photo Instrumentation Engineers)*, Vol. 8906, pp. 890626-1–890626-6.

[6] Mondal, R., Mukopadhyay, A. and Basak, D. (2013), "Embedded System of DC Motor Closed Loop Speed Control based on 8051 Microcontroller", *Procedia Technology*, Vol. 10, pp. 840–848, Jan. 2013.

[7] Alexandridis, A.T. and Konstantopoulos, G.C. (2014), "Modified PI Speed Controllers", *Control Engineering Practice*, Vol. 23, pp. 14–21, Feb. 2014.

[8] Butler, H., Honderd, G. and Amerongen, J.V. (1989), "Model Reference Adaptive Control of Direct Drive DC Motor", *IEEE Control System Magzine*, pp. 80–84.

[9] Beltran-Carbajal, F., Favela-Contrears, A., Valderrabano-Gonzalez, A. and Rosas-Caro, J.C. (2014), "Output Feedbcak Control for Robust Tracking of Position Trajectories for DC Electric Motors", *Electric Power System Research*, Vol. 107, pp. 183–189, Feb. 2014.

[10] Knudsen, M. and Jensen, J.G. (1995), "Estimation of Non-linear DC Motor Models using a Sensitivity Approach", in *Third European Control Conf.*, ECC, Vol. 95.

[11] Al-Qasar, A.A. and Othman, M.Z. (2008), "Experimental Determination of Electrical and Mechanical Parameters of DC Motor using Genetic Elman Neural Network", *Journal of Engirering Science and Technology*, Vol. 3, No. 2, pp. 190–196.

[12] Bature, A.A., Muhammad, M. and Abdullahi, A.M. (2013), "Parameter Identification of a Class of DC Motor", *International Journal of Research in Engineering and Science(IJERS)*, Vol. 1, No. 5, pp. 69–72, Sep. 2013.

[13] Salah, M.S., Gaza, P. and Abdeltai, M. (2009), "Parameters Identification of Permanent Magnet DC Motor", *Proceedings of the 29th IASTED International Conference*, Vol. 675, pp. 177–183.

[14] Rai, N. and Rai, B. (2013), "Neural Network based Closed Loop Speed Control of DC Motor using Arduino UNO", *International Journal of Engineering Trends and Technology*, Vol. 4, Issue 2, pp. 137–140.

[15] Ohri, Salim, J. (2015), "Fuzzy based Speed Control of DC Motor using Labview", *WSEAS Transaction on Systems and Control*, Vol. 10, pp. 154–159.

[16] Morales, R., Somolinos, J.A. and Sira-Ramirez, H. (2014), "Control of DC Motor using Algebraic Derivative Estimation with Real Time Experiments", *Measurement*, Vol. 47, pp. 401–417, Jan. 2014.

[17] Basilio, J.C. and Matos, S.R. (2002), "Design of PI and PID Controllers with Transient Performance Specification", *IEEE Trans. Education*, Vol. 45, Issue 4, pp. 364–370.

[18] Onate, C.U. and Molina, J.K. (2014), "Characterization, Simulation and Implementation of a New Dynamic Model for a DC Servomotor", *IEEE Latin American Transaction*, Vol. 12, pp. 997–1004, Issue 6, Sept. 2014.

[19] Qureshi, M.S., Swarnkar, P. and Gupta, S. (2016), "Assesment of DC Servo Motor with Sliding Mode Control Approach", *IEEE Conference on Control Measurement and Instrumentation*, Feb. 2016.